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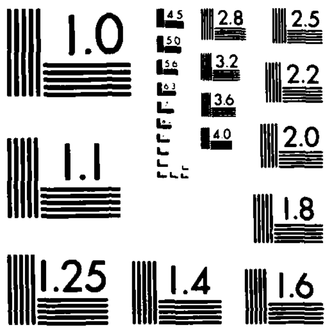
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FOREIGN TECHNOLOGY DIVISION

A SMALL-SCALE SELF-EXCITED ROTOR ELECTROSTATIC GENERATOR

BY

A.F. Kalganov

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EDITED TRANSLATION

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О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

**ye* initially, after vowels, and after ъ, ь; *e* elsewhere.
When written as ё in Russian, transliterate as yё or ё.

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Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$sinh^{-1}$
cos	cos	ch	cosh	arc ch	$cosh^{-1}$
tg	tan	th	tanh	arc th	$tanh^{-1}$
ctg	cot	cth	coth	arc cth	$coth^{-1}$
sec	sec	sch	sech	arc sch	$sech^{-1}$
cosec	csc	csch	csch	arc csch	$csch^{-1}$

Russian	English
rot	curl
lg	log

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A SMALL-SCALE SELF-EXCITED ROTOR ELECTROSTATIC GENERATOR

A. F. Kalganov

Electrostatic generators, as sources of high direct current voltage, are being used more and more extensively in science and technology [1-5]. Rotor electrostatic generators with conductor-carriers occupy a significant place among these generators; rotor electrostatic generators develop a voltage in the hundreds of kV and have the advantage that they can be made self-exciting. This considerably simplifies servicing and operation of the generators and is especially important in a small-scale design.

Theoretical and experimental works on electrostatic generators with conductor-carriers in the last 20 years have led to the development of various types of such generators [6-23]. Soviet scientists have made a great contribution to these works [6-13, 22]. However, the procedure for engineering calculation of certain types of generators still has not been adequately developed. In particular, the Zan calculation [23] does not take into account the effect of parasitic capacitances in generators of disc and cylinder types. A derivation of calculation formulae for a special case of a cylindric generator with single charging, with consideration for parasitic capacitances, is presented below.

An experimental model of a small-scale self-excited ESG [electrostatic generator] of this type for 75 kV, 100 μA, has been calculated according to the procedure presented and constructed, and an investigation has been performed on it.

1. DERIVATION OF CALCULATION FORMULAE

A simple diagram of a generator of the type in question is shown in Fig. 1. The stator plates are represented by semicircles 1 and 2, and the two rotor carriers, which are insulated from each other, are indicated by semicircles 3 and 4 which are concentric with the first two semicircles. The collector plates 5 and 6 and brushes 7 and 8 serve for applying and taking off charges. R is the load resistance.

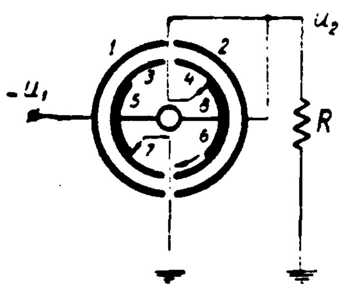

Fig. 1. Diagram of simple ESG with conductor-carriers.

The main formulae characterizing the operation of a simple generator according to the design of Fig. 1 on the condition of the absence of parasitic capacitances and production of maximum power have the following form [4]:

$$I=2nq=2nC_1U_1, \tag{1}$$

$$U_2=\frac{U_0}{2}=U_1, \tag{2}$$

$$P_0=2nC_1\left(\frac{U_0}{2}\right)^2=2nC_1U_1^2. \tag{3}$$

Here I and U_2 are the output current and voltage of the generator; q_1 is the charge transferred by the carrier in one revolution of the rotor; P_0 is the maximum generator power; U_1 is the excitation voltage; C_1 is the maximum capacitance between the carrier and the excitation plate 1; n is the number of rotor revolutions; U_0 is the maximum acceptable voltage between the excitation plate and the carrier, defined as

$$U_0-Ed, \tag{4}$$

where E is the average working intensity of the electrical field in the gap between the rotor and the stator, and d is the magnitude of the gap.

As one can see from the book by A. A. Vorob'yev [2], the generator output voltage U_2 for the conditions adopted is equal in its absolute value to the excitation voltage U_1; i.e., the voltage increase factor $k=U_2/U_1$ is equal to one. Actually, due to the presence of parasitic capacitances, the output voltage is less than the excitation voltage ($k<1$).

We shall consider the total parasitic (or residual) capacitance as the capacitance in relation to the ground and designate it as

$$C_3=\alpha C_1, \tag{5}$$

where α is the parasitic capacitance coefficient, indicating the proportion of the maximum capacitance C_1 to which the parasitic capacitance C_3 corresponds. Due to the capacitance C_3, a residual charge will be preserved on the carrier in each revolution of the rotor; the residual charge is as follows:

$$q_2=C_3U_2= C_1U_2, \tag{6}$$

and the load current (on the condition $U_0=U_1+U_2$) will be

$$I=2n(q_1-q_2)=2n(C_1U_1-\alpha C_1U_2)=2nC_1[U_0-(1+\alpha)U_2]. \tag{7}$$

Then the power developed by the generator is defined as

$$P=IU=2nC_1[U_0-(1+\alpha)U_2]U_2. \tag{8}$$

The most profitable operating mode of the generator is the maximum power mode. At U_0=const, the voltage U_2 is the only independent variable [8]. Taking a derivative from P in regard to U_2 and setting it equal to zero (following the procedure of [4]), we find the conditions under which the power is maximal:

$$U_2=\frac{U_0}{2}\cdot\frac{1}{1+\alpha} \tag{9}$$

and

$$U_1=U_0-U_2=\frac{U_0}{2}\cdot\frac{1+2\alpha}{1+\alpha}. \tag{10}$$

In this case, the expression for the maximum power will take on the form

$$P_m=2nC_1\left(\frac{U_0}{2}\right)^2\cdot\frac{1}{1+\alpha}, \tag{11}$$

and the voltage increase factor will amount to a value

$$k=\frac{U_2}{U_1}=\frac{1}{1+2\alpha}<1. \tag{12}$$

Comparing (3) to (11), we find

$$P_m=\frac{1}{1+\alpha}P_0. \tag{13}$$

Indirect evaluation according to the data of [15] indicates that for different designs of generators of this type, the parasitic capacitance factor α=0.2-0.5. Assume, for example, that α=0.2. Then from (12) and (13) we find

$$P_m=0.83P_0 \text{ and } k=0.715.$$

As one can see from the data presented, parasitic capacitances cause a significant decrease in generator power; the

maximum power occurs at reduced values of the output voltage. Operation at high voltages leads to still greater reduction of the generator power.

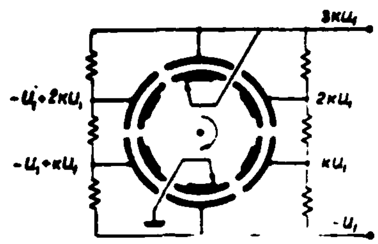

Fig. 2. Diagram of high-voltage generator.

For obtaining high voltage values, one uses not one but several pairs of carriers and stator plates; the intermediate stator plates are kept under the appropriate potentials, by a potentiometer, for example. Figure 2 presents a diagram of a generator with three pairs of plates. The optimum number of pairs of generator plates is determined according to an empirical formula [15]:

$$N=\frac{m}{2}=(0.15-0.2)\frac{r}{d}, \qquad (14)$$

where m is the number of rotor carriers, which is equal to the number of stator plates, and r is the rotor radius. Assuming that

$$U_0=U_1+U_2', \qquad (15)$$

where U_2 is the potential of a carrier situated under the first intermediate stator plate, we find that for a generator with N pairs of plates, the following equations will be valid:

$$P_m=mnC_1\left(\frac{U_0}{2}\right)^2\cdot\frac{N}{1+\alpha N}, \qquad (16)$$

$$I=mnC_1U_1\frac{1+\alpha N}{1+2\alpha N}=mnC_1\frac{U_0}{2}, \qquad (17)$$

$$U_2 = N U_2'. \tag{18}$$

$$k = \frac{1}{1+2\alpha N}. \tag{19}$$

$$U_2' = k U_1 = \frac{U_0}{2} \cdot \frac{1}{1-\alpha N}. \tag{20}$$

$$U_1 = U_0 - U_2' = \frac{U_0}{2} \cdot \frac{1+2\alpha N}{1-\alpha N} \tag{21}$$

2. CALCULATION OF A GENERATOR

The source data for calculation of a generator, in addition to the output voltage and current, were as follows: the inner diameter of the generator casing D_1=99 mm; the working electrical field intensity in the generator E=300 kV/cm; the rotor rotation rate n=3000 r/min=50 r/s.

The optimum number of pairs of plates N=2 was obtained from preliminary calculations of versions of the generator. The calculation parasitic capacitance factor was adopted as α=0.2. For the conditions adopted, we find a generator voltage increase factor (see equation (20))

$$k = \frac{1}{1+2\alpha N} = \frac{1}{1+2 \cdot 0{,}2 \cdot 2} = 0{,}556.$$

The potential of carriers under an intermediate stator plate, according to equation (18),

$$U_2' = \frac{U_2}{N} = \frac{75}{2} = 37{,}5 \text{ kV}.$$

Then using equations (20), (21) and (4), we find

$$U_1 = \frac{U_2'}{k} = \frac{37{,}5}{0{,}556} = 67{,}5 \text{ kV},$$

$$U_0 = U_2' + U_1 = 37{,}5 + 67{,}5 = 105 \text{ kV},$$

and

$$d = \frac{U}{E} = \frac{105}{300} = 0{,}35 \text{ cm.}$$

From equation (17) we define the maximum capacitance of the stator carrier-plate system:

$$C_1 = \frac{2I}{mnU} = \frac{2\cdot 100\cdot 10^{-6}}{4\cdot 50\cdot 105\cdot 10^{6}} = 9{,}52\cdot 10^{-12} \text{ F} = 9.52 \text{ pF.}$$

Here m=2N=4.

For calculating the necessary surface area of one carrier, we use the formula for the capacitance of a plane capacitor, since d is much less than r (r is the rotor radius):

$$S = \frac{d\cdot C_1}{\varepsilon_0} = \frac{0{,}35\cdot 10^{-2}\cdot 9{,}52\cdot 10^{-12}}{8{,}85\cdot 10^{-12}} = 4\cdot 10^{-3} \text{ m}^2 = 40 \text{ cm}^2.$$

The rotor and stator plate thickness [15] is adopted as equal to the magnitude of the gap between the rotor and stator; i.e., 0.35 cm. In establishing the gap between the stator and the inner surface of the casing as 0.4 cm based on design considerations, we find the outer diameter of the rotor: D_2=7.7 cm. In adopting a value of the gap between adjacent carriers as 2d, we define the linear dimensions of the carriers in relation to the circumference of the rotor,

$$b = \frac{\pi D_2}{m} - 2d = \frac{\pi 7{,}7}{4} - 7 = 5{,}3 \text{ cm,}$$

from which the length of the main rotor carrier

$$l = \frac{S}{b} = \frac{40}{5{,}3} = 7{,}55 \text{ cm.}$$

Taking into account the need for rounding off, the carrier length is adopted as 9 cm.

A smaller auxiliary rotor is used for providing self-excitation of the generator [1, 3]. The length of the auxiliary rotor in our case was 1.2 cm. A cut-away view of the generator

and a diagram of its connections are shown in Fig. 3.

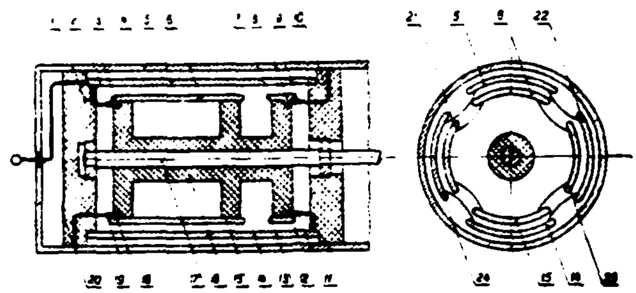

Fig. 3. Diagram of self-excited generator: 1, 10 - flanges; 2, 9, 11, 19 - brushes; 3, 8, 12, 18 - collector plates; 4 - casing; 5, 14, 22, 24 - stator plates; 6, 15, 21, 23 - main rotor carriers; 7, 13 - auxiliary rotor carriers; 20 - high-voltage outlet.

3. STRUCTURAL CONFIGURATION OF THE GENERATOR

Organic glass was used as the insulating material. Duralumin was used for reducing the weight of the metal plates. The rounded edges of the plates have a contour similar to the theoretical contour [15]. The rotor face surfaces, over which the brushes slide, are coated with fluoroplastic-4, which improves sliding of the brushes between collector plates, which are made of brass in the form of arcs whose angular dimension amounts to approximately half that of the carriers. The brass brushes have the form of shells pressed against the rotor faces by coil springs [24].

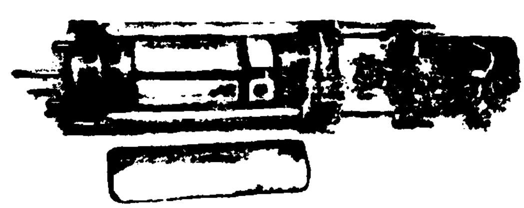

Fig. 4. External view of generator with motor. One stator plate has been removed.

An overall view of a generator with a motor of the DShS-2 type is shown in Fig. 4. Strictly speaking, the generator occupies a volume of 2 dm^3 and weighs less than 2 kg. The generator with the motor is placed in a cylindric steel casing with inner and outer diameters of 99 and 109 mm, respectively, and a length of 0.5 m, equipped with covers with outlets for high and low voltages.

Food carbon dioxide under a pressure of 22 at was used as the filler gas in the generators.

4. TEST RESULTS

A generator with outside excitation was tested for determining the actual value of the parasitic capacitance factor; for this purpose, the auxiliary rotor was excluded, and the excitation voltage was fed from an outside current source. Figure 5 presents volt-ampere characteristics of the generator for different fixed values of the voltage U_1, under otherwide equal conditions. Since the generator was not calculated for feeding with outside voltage, the excitation voltage could not be raised above 24 kV due to breakdowns in the feeding cable.

The characteristics have the form of straight lines [6] intersecting the voltage axis at points corresponding to the idling voltage and the current axis at points corresponding to the short circuiting current. The ratio of the excitation voltage U_1 to the idling voltage U_{xx} is constant in all cases and has the following value:

$$\frac{U_1}{U_{xx}} = \alpha = 0.4.$$

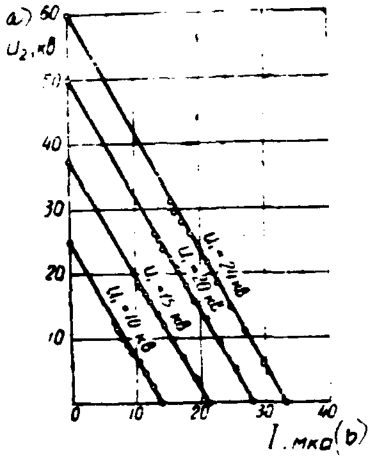

Fig. 5. Volt-ampere characteristics of a generator with outside excitation. n=2100 r/min.
Key: (a) kV; (b) μA.

The value of the coefficient α attests to the fact that the parasitic capacitance in the generator is significant: twice the calculation value adopted. It is natural, therefore, that the electrical parameters of the generator should differ from the values calculated previously. Actually, using the appropriate equations and substituting a value α=0.4 into them, we find that the generator should develop a maximum power

$$P_м = mnC_1\left(\frac{U_1}{2}\right)^2 \cdot \frac{k}{1-\alpha k} = 4\cdot 5\cdot 9.52\cdot 10^{-12}\left(\frac{105\cdot 10^3}{2}\right)^2 \cdot \frac{2}{1-0.4\cdot 2} \approx 5.8 \text{ W}$$

at U_1=76 kV, U_2'=29 kV, and k=0.384. The output voltage of the generator should have the following value:

$$U_2 = NU_2' = 2\cdot 29 = 58 \text{ kV}$$

at a calculation current I=100 μA.

An actual maximum power of 5 W was obtained for a self-excited generator at a voltage of 54.5 kV and a current of 91 μA. The small discrepancy in generator parameters obtained

by calculation and experimentally is explained by the fact that the calculation electrical field intensity in the generator was not achieved. Substituting the actual value into the expression for the maximum power, we find that U_0=97 kV instead of the calculated 105 kV. According to the value of U_0 obtained in this manner, the possible values of the output voltage and current are finally determined:

$$U_2 = 2U' = 2\left(\frac{U_0}{2} \cdot \frac{1}{1-[illegible]}\right) = 2\left(\frac{97}{2} \cdot \frac{1}{1-0.4[illegible]}\right) = 74 \text{ kV}$$

and

$$I = [illegible] \frac{U_0}{2} = 4 \cdot 50 \cdot 9.52 \cdot 10^{-[illegible]} \cdot \frac{97 \cdot [illegible]}{2} = 92 \cdot 10^{-[illegible]}\ a = 92\ \mu\text{A}.$$

The values computed should coincide with experimental values, which was essentially achieved.

A value of U_0=97 kV also makes it possible to determine the actual average working intensity of the electrical field in the gap,

$$E = \frac{U_0}{d} = \frac{97}{0.35} = 278 \text{ kV/cm}.$$

CONCLUSIONS

Investigation of the generator constructed demonstrated satisfactory agreement of experimental data with calculation results obtained with consideration for the actual value of the parasitic capacitance factor, confirming the accuracy of the refined procedure for calculating ESG of this type.

In conclusion, the author wishes to express his gratitude to Professor A. A. Vorob'yev, doctor of physical and mathematical sciences, for directing this work, Doctor of Physical and Mathematical Sciences Ye. K. Zavadovskaya for discussing a

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LITERATURE

1. U. Neubert, Elektrostatik in der Technik, München 1954
2. А. А. Воробьев, Сверхвысокие электрические напряжения. Госэнергоиздат, М.-Л., 1955
3. Z. Zan, Electrotechn. Obz., 45, T36, 1956.
4. N. J. Felici, Electrostatische Hochspannung- Generatoren. G. Braun Karlsruhe, 1957.
5. Под ред. акад. А. К. Вальтера. Электростатические генераторы. Атомиздат. М. 1959.
6. А. Ф. Иоффе, ЖТФ, **9**, 2071, 1939.
7. Б. М. Гохберг, А. Ф. Иоффе и Н. М. Рейнов, ЖТФ, **9**, 2081, 1939.
8. С. А. Бобковский, Б. М. Гохберг, А. Ф. Иоффе и Н. М. Рейнов, ЖТФ, **9**, 2090, 1939.
9. Б. М. Гохберг, А. Ф. Иоффе и Н. М. Рейнов, ЖТФ, **9**, 2094, 1939.
10. Б. М. Гохберг, ЖТФ, **10**, 177, 1940.
11. С. А. Бобковский, ЖТФ, **10**, 1404, 1940.
12. А. Ф. Иоффе и Б. М. Гохберг, ЖТФ, **11**, 617, 1941.
13. А. Е. Каплянский, Введение в общую теорию электрических машин, Госэнергоиздат, М.-Л., 1941.
14. N. J. Felici, J. Phys. et Rad. **8**, 1, 1947.
15. N. J. Felici, J. Phys. et Rad. **9**, 66, 1948.
16. N. J. Felici, J. Phys. et Rad. **10**, 437, 1949.
17. N. J. Felici, Rev. Gen. Electric. **59**, 479, 1950
18. N. J. Felici, L' Onde Electrique. **31**, 205, 1951.
19. N. J. Felici, Schweiz. Techn. Z. **11**, 145, 1953.
20. N. J. Felici, Brit. J. Appl. Phys. № 2, 562, 1953
21. U. Neubert, ETZ-B, № 6, 199, 1954.
22. А. А. Бальчитис, „Известия вузов – „Электромеханика", № 10, 55, 1959.
23. Z. Zan, Electrotechn. Obz. **47**, T23, 1958.
24. П. П. Галинский. Дипломная работа. Томск. 1958.

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